TOWARD GREEN BUILDINGS:

DESIGN, DEVELOPMENT AND PERFORMANCE EVALUATION OF A SOLAR-POWERED ABSORPTION COOLING SYSTEM

Thesis by

Vahid Vakiloroaya

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Supervisor:

A/Prof Quang Ha

Co-Supervisor:

Prof Bijan Samali

Certificate of Original Authorship

I hereby declare that this submission is my own work and has not previously been submitted for a degree and to the best of my knowledge it does not contain materials published and written by another person, nor the materials which have been accepted for the award of any other degree except where due acknowledgement is made in this thesis.

I, in addition, certify that this thesis has been written by me except to the extent that assistance from others is fully acknowledged. I also certify that all information sources and literature quoted are indicated in this thesis.

Vahid Vakiloroaya

ABSTRACT

TOWARD GREEN BUILDINGS: DESIGN, DEVELOPMENT AND PERFORMANCE EVALUATION OF A SOLAR-POWERED ABSORPTION COOLING SYSTEM

Conventional HVAC systems rely heavily on energy generated from fossil fuels, which are being rapidly depleted. This together with a growing demand for cost-effective infrastructure and appliances has necessitated new installations and major retrofits in occupied buildings to achieve energy efficiency and environmental sustainability. As well as contributing to negative environmental outcomes, HVAC system usage is having a serious impact on electrical infrastructure. As such, the development of clean energy air conditioning units remains an urgent engineering challenge. Solar HVAC systems, which convert thermal energy into cool air, are known to be an efficient source of heating and cooling. Unlike traditional HVAC systems, solar air conditioning units produce maximum cooling capacity when the sun is fierce; that is, they are most efficient during the hottest part of the day, in stark contrast to traditional air conditioning units, which are less effective as temperatures increase.

This study represents a synergetic framework of system identification, design, development and performance evaluation of a newly-configured air conditioning system to target energy efficiency and environmental sustainability in buildings. In this study, we have originally designed and developed a single-effect lithium bromide (LiBr)-water absorption air-conditioning system in which hot water is fully supplied by vacuum solar collectors without using any other energy sources such as gas or electricity. Water-cooled condenser of the chiller is supported by a cross-flow cooling tower. In this system, by using water as the working fluid (refrigerant), one can avoid the use of ozone-depletion chlorofluorocarbons and hydro chlorofluorocarbons. Thermodynamic and heat transfer models for absorption chiller components are described in detail. Using these models, a computer simulation software named ABSYS is developed to design the absorption chiller and drive its optimum operating conditions.

Thermodynamic design data for single-effect absorption chiller are presented together with the possible combinations of the operating temperatures and the corresponding concentrations in the absorber and generator. The effect of various operating conditions on the performance and output of the absorption refrigeration system are then evaluated.

Another computer code is developed by using TRNSYS to evaluate the transient performance of the entire system. Several field tests are carried out to demonstrate the technical feasibility of the system. The utilisation of the solar energy as the heat input to the generator of the absorption chiller is reported. Since Australia has great solar resources and large air condition demand, this system can be uniquely suited in Australia. However, absorption cooling technology and especially the application of solar energy in this technology is still in its infancy in Australia.

The proposed design can be helpful to accelerate a global clean society to achieve its sustainable targets, especially in Australia, which has untapped high potential to become a World's green country. Work on this thesis, supported partially by The NSW Government through its Environmental Trust, is therefore aimed to design and explore sustainable solar-powered absorption air conditioning system to show the viability of this system in Australia and reduce the energy consumption of an air-conditioned building by using this eco-friendly cooling technology.

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Vahid Vakiloroaya

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NOMENCLATURE

A	area (m^2)
A_{cross}	cross sectional area (m^2)
A_m	mean surface area (m^2)
A_o	outside area (m^2)
A_V	surface area of water droplets per tower cell exchange volume (m^2)
Cap	capacity (kW)
COP	coefficient of performance
C_p	heat capacity (kJ/(kg°C))
CR	circulation ratio
CV	coefficient of variance
C_{cover}	cloudiness factor
C_s	average saturation slope of the air enthalpy versus temperature
D	diameter (m)
D_e	equivalent diameter (m)
e_o	emittance
Fr_{Dl}	inside fouling factor
Fr_{De}	outside fouling factor
f_i	design energy input fraction
f_o	design energy input fraction
g	gravitational acceleration (m^2/s)
h	enthalpy (kJ/kg)
$h_{s,w,e}$	Enthalpy of the saturated air entering the cooling coil (kJ/kg)
I_t	Total solar radiation intensity (W/m^2)
I	Total horizontal radiation (W/m^2)
I_{bT}	beam radiation incident (W/m^2)

I_d	diffuse radiation incident (W/m^2)
k	thermal conductivity (W/m °C)
k_T	ratio of total radiation on the horizontal surface to the extraterrestrial radiation
L	length (m)
L_d	thermal developing length (m)
M	mass (kg)
$\dot{m}$	mass flow rate (kg/s)
n	number of tubes
Nu	Nusselt number
Ntu	overall number of transfer units
P	pressure (mm Hg)
P_w	wetted area (m^2)
P_{atm}	atmospheric pressure
P_h	atmospheric pressure at the height of h
Pr	Prandtl number
Q	heat transfer capacity (kW)
RE	relative error
Re	Reynolds number
R_r	ratio of the reflected radiation on the tilted surface to the total radiation on the horizontal surface
$RMSE$	root mean square error
RH	relative humidity
s_x	standard deviation
T	temperature (°C)
ΔT_m	logarithmic mean temperature difference (°C)
t	time (sec)
t_p	plate thickness (m)
U	overall heat transfer coefficient (kW/(m^2°C))

v	Water velocity (m/s)
V_{cell}	total cooling tower cell exchange volume (m^3)
W_p	input work of pump (kW)
X	LiBr-water concentration
$y_{data,i}$	measured variables
$y_{data,m}$	average value of data
μ	absolute viscosity (kg/m.s)
ν	kinematic viscosity (m^2/s)
α	heat transfer coefficient (kW/m^2 °C)
α_i	heat transfer coefficient inside the tube (kW/(m^2 °C))
α_o	heat transfer coefficient outside the tube (kW/(m^2 °C))
α_d	average heat transfer coefficient in thermal developing region (kW/(m^2 °C))
α_c	convective heat transfer coefficient due to evaporation of the liquid films (kW/(m^2 °C))
ρ	density (kg/m^3)
ρ_{gr}	ground reflectance
β	solar collector slop
γ	surface azimuth
γ_s	solar azimuth angle
ω	mean hour angle of time step
δ	solar declination angle
λ	thermal diffusivity (m^2/s)
η	second law efficiency
η_{col}	solar collector efficiency
ε	effectiveness
ψ	solar altitude angle
θ	angle of incidence of beam radiation on the surface
θ_z	solar zenith angle

φ	latitude
τa	transmittance-absorptance product

Subscripts

a	air, absorber
act	actual
adp	dew-point
aux	auxilury
amb	ambient
atm	atmospheric
b	beam
c	condenser
cap	capacity
cc	cooling coil
col	collector
chw	chilled water
cw	cooled water
ct	cooling tower
Cu	cupper
d	diffuse
db	dry-bulb
e	evaporator, entering
equ	equvalent
elec	electricity
f	fluid
g	generator
gl	glass
gr	ground
h	height
hw	hot water
hx	heat exchanger
k	Kelvin

i	inside
l	liquid
m	mean
max	maximum
n	normal
nom	nominal
o	outlet, outside
pl	plate
pred	predicted
ref	refrigerant
sat	saturated
s	solution
sh	superheated
ss	strong solution
sup	supply
t	tank
tr	transition
v	vapour
w	Water, wet
ws	weak solution
x	point on the cooling coil where condensation beings

ABBREVIATION

ABSYS	Absorption System Simulation
AIRAH	Australian Institute of Refrigeration, Air Conditioning and Refrigeration
ARA	Australian Refrigeration Association
ASHP	Air Source Heat Pump
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
AUD	Australian Dollar
CLF	Cooling Load Factors
CLTD	Cooling Load Temperature Differences
CO_2	Carbon Dioxide
CO_2-e	Carbon Dioxide Equivalent
CSIRO	Commonwealth Scientific and Industrial Research Organization
CV	Coefficient of Variance
DEC	Direct Evaporative Cooling
DP	Dew-Point
DX	Direct Expansion
ECC	Evaporative-Cooled Condenser
GHG	Greenhouse Gas
GSHP	Ground Source Heat Pump
GWh	Gigawatt hour
GWP	Global Warming Potential
HVAC	Heating, ventilation and air conditioning
kWh	Kilowatt hour
LMTD	Logarithmic Mean Temperature Difference
ODP	Ozone Depletion Potential
Mt	Megatonne, or million tonnes
PJ	Petajoule
PCM	Phase Change Material
PV	Photovoltaic

PLC	Programmable Logic Controller
RE	Relative Error
RMSE	Root Mean Square Error
RT	Refrigeration Tons
SCL	Solar Cooling Load
TFM	Transfer Function Method
TRNSYS	Transient System Simulation
VB	Visual Basic